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JC843 U.S. PTO 09/724740 11/28/00

# UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

**Attorney Docket No.** 80398.P386
(maximum 12 characters)
**First Named Inventor** James J. Carrig

**Title:** ROBUST TIME DOMAIN BLOCK DECODING

**Express Mail Label No.** EL 617 210 375 US

**ADDRESS TO:** **Assistant Commissioner for Patents**
**Box Patent Application**
**Washington, D. C. 20231**

## APPLICATION ELEMENTS

**See MPEP chapter 600 concerning utility patent application contents.**

1. X **Fee Transmittal Form (e.g., PTO/SB/17)**
(Submit an original, and a duplicate for fee processing)

2. X **Applicant Claims Small Entity Status. (37 CFR 1.27)**

3. X **Specification (Total Pages 24)**
(preferred arrangement set forth below)
- Descriptive Title of the Invention
- Cross Reference to Related Applications
- Statement Regarding Fed sponsored R & D
- Reference sequence listing, a table, or a computer program listing appendix
- Background of the Invention
- Brief Summary of the Invention
- Brief Description of the Drawings (if filed)
- Detailed Description
- Claim(s)
- Abstract of the Disclosure

4. X **Drawings(s) (35 USC 113) (Total Sheets 7)**

5. X **Oath or Declaration (Total Pages 4)**
   a. X Newly Executed (Original or Copy)
   b. ____ Copy from a Prior Application (37 CFR 1.63(d))
   (for Continuation/Divisional with Box 17 completed)
      i. ___ DELETIONS OF INVENTOR(S) Signed statement attached deleting inventor(s) named in the prior application, see 37 CFR 1.63(d)(2) and 1.33(b).
   c. ____ Unsigned.

6. ______ **Application Data Sheet. (37 CFR 1.76)**

7. ______ CD-ROM or CD-R in duplicate, large table or Computer Program (Appendix)

8. ______ Nucleotide and/or Amino Acid Sequence Submission
(if applicable, all necessary)
   a. ____ Computer Readable Form (CRF)
   b. ____ Specification Sequence Listing on.
      i. _________CD-ROM or CD-R (2 copies); or
      ii. _________ paper
   c. ____ Statement verifying identity of above copies

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## ACCOMPANYING APPLICATION PARTS

9. _X_ **Assignment Papers (cover sheet & documents(s))**

10. ____ a. Separate 37 CFR 3.73(b) Statement (where there is an assignee)

____ b. Power of Attorney

11. ____ English Translation Document (if applicable)

12. ____ a. Information Disclosure Statement (IDS)/PTO-1449

____ b. Copies of IDS Citations

13. ____ **Preliminary Amendment**

14. _X_ **Return Receipt Postcard (MPEP 503) (Should be specifically itemized)**

15. ____ Certified Copy of Priority Document(s) (if foreign priority is claimed)

16. ____ Request and Certification under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or its equivalent.

17. _X_ Other: Copy of postcard and Certificate of Express Mailing pursuant to CFR §1.10.

---

**18A. If a CONTINUING APPLICATION,** check appropriate box and supply the requisite information:

____ **Continuation** ____ **Divisional** ____ **Continuation-in-part (CIP)**

**Of Prior Application No.:** ________ **Examiner** ________ **Group Art Unit** ________

(which is a ___ continuation/ ___ divisional/ ___ CIP of prior application no. ________,
which is a ___ continuation/ ___ divisional/ ___ CIP of prior application no. ________) (List entire chain of priority)

**For CONTINUATION AND DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.**

**18B. Statement under 37 CFR 3.73(b) for continuing application:**
**The undersigned states that ________________ (name of assignee) is the assignee of the entire right, title, and interest in the accompanying patent application by virtue of an assignment recorded in the Patent and Trademark Office at Reel. No. ________ Frame No. ________ (or a copy of which is attached).**

---

**19. Correspondence Address**

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(Insert Customer No. or Attach Bar Code Label here)

or

_X_ Correspondence Address Below

NAME Jeffrey S. Smith

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CITY Los Angeles STATE California ZIP CODE 90025-1026

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---

**Name (PRINT/TYPE):** Jeffrey S. Smith **Registration No.:** 39,377

**Signature:** Jeffrey S. Smith **Date:** November 28, 2000

## EXPRESS MAIL CERTIFICATE OF MAILING

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Tina Domingo

(Typed or printed name of person mailing paper or fee)

(Signature of person mailing paper or fee)

11-28-2000

(Date signed)



Serial/Patent No.: * *

Filing/Issue Date: Herewith

Client: Sony Electronics, Inc.

Title: Robust Time Domain Block Decoding

BSTZ File No.: 80398.P386

Atty/Secty Initials: MES/JSS/td

Date Mailed: 11-28-2000

Docket Due Date: * *

**The following has been received in the U.S. Patent & Trademark Office on the date stamped hereon:**

- ☐ Amendment/Response (____ pgs.)
- ☐ Appeal Brief (____ pgs.) (in triplicate)
- ☒ Application - Utility (24 pgs., with cover and abstract)
- ☐ Application - Rule 1.53(b) Continuation (____ pgs.)
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- ☐ Application - Rule 1.53(b) CIP (____ pgs.)
- ☐ Application - Rule 1.53(d) CPA Transmittal (____ pgs.)
- ☐ Application - Design (____ pgs.)
- ☐ Application - PCT (____ pgs.)
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- ☒ Declaration & POA (4 pgs.) (Executed)
- ☐ Disclosure Docs & Orig & Copy of Inventor's Signed Letter (____ pgs)
- ☒ Drawings: 7 # of sheets includes 8 figures
- ☒ Express Mail No. EL617210375US
- ☐ ________ Month(s) Extension of Time
- ☐ Information Disclosure Statement & PTO-1449 (__ pgs.)
- ☐ Issue Fee Transmittal
- ☐ Notice of Appeal
- ☐ Petition for Extension of Time
- ☐ Petition for ________
- ☒ Postcard
- ☐ Power of Attorney (____ pgs.)
- ☐ Preliminary Amendment (____ pgs.)
- ☐ Reply Brief (____ pgs.)
- ☐ Response to Notice of Missing Parts
- ☐ Small Entity Declaration for Indep Inventor/Small Business
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- ☒ Fee Transmittal, in duplicate
- ☒ Check No. 39222 Amt. $710.00
- ☒ Check No. 39224 Amt: $40.00
- ☐ Other: ________

# FEE TRANSMITTAL FOR FY 2001

**TOTAL AMOUNT OF PAYMENT ($)** $750.00

**Complete if Known:**
**Application No.** Not Assigned
**Filing Date** November 28, 2000 (Concurrently Herewith)
**First Named Inventor** James J. Carrig
Group Art Unit Not Assigned
Examiner Name Not Assigned
Attorney Docket No. 80398.P386

**METHOD OF PAYMENT** (check one)

1. [ X ] **The Commissioner is hereby authorized to charge indicated fees and credit any over payments to:**

   **Deposit Account Number** 02-2666
   **Deposit Account Name** ______

   [ ] **Charge Any Additional Fee Required Under 37 CFR 1.16 and 1.17**

   [ ] **Applicant claims small entity status. See 37 CFR 1.27**

2. X **Payment Enclosed:**
   X **Check**
   ___ **Credit Card**
   ___ **Money Order**
   ___ **Other**

## FEE CALCULATION

### 1. BASIC FILING FEE

| Large Entity Fee Code | Large Entity Fee ($) | Small Entity Fee Code | Small Entity Fee ($) | Fee Description | Fee Paid |
|---|---|---|---|---|---|
| 101 | 710 | 201 | 355 | Utility application filing fee | 710.00 |
| 106 | 320 | 206 | 160 | Design application filing fee | |
| 107 | 490 | 207 | 245 | Plant filing fee | |
| 108 | 710 | 208 | 355 | Reissue filing fee | |
| 114 | 150 | 214 | 75 | Provisional application filing fee | |

**SUBTOTAL (1) $ 710.00**

### 2. EXTRA CLAIM FEES

| | | | Extra Claims | | Fee from below | | Fee Paid |
|---|---|---|---|---|---|---|---|
| Total Claims | 15 | −20** = | 0 | X | | = | |
| Independent Claims | 3 | −3** = | 0 | X | | = | |
| Multiple Dependent | | | | | | = | |

****Or number previously paid, if greater; For Reissues, see below.**

| Large Entity Fee Code | Large Entity Fee ($) | Small Entity Fee Code | Small Entity Fee ($) | Fee Description |
|---|---|---|---|---|
| 103 | 18 | 203 | 9 | Claims in excess of 20 |
| 102 | 80 | 202 | 40 | Independent claims in excess of 3 |
| 104 | 270 | 204 | 135 | Multiple dependent claim, if not paid |
| 109 | 80 | 209 | 40 | **Reissue independent claims over original patent |
| 110 | 18 | 210 | 9 | **Reissue claims in excess of 20 and over original patent |

**SUBTOTAL (2) $ 0.00**

## FEE CALCULATION (continued)

### 3. ADDITIONAL FEES

| Large Entity Fee Code | Large Entity Fee ($) | Small Entity Fee Code | Small Entity Fee ($) | Fee Description | Fee Paid |
|---|---|---|---|---|---|
| 105 | 130 | 205 | 65 | Surcharge - late filing fee or oath | |
| 127 | 50 | 227 | 25 | Surcharge - late provisional filing fee or cover sheet | |
| 139 | 130 | 139 | 130 | Non-English specification | |
| 147 | 2,520 | 147 | 2,520 | For filing a request for ex parte reexamination | |
| 112 | 920* | 112 | 920* | Requesting publication of SIR prior to Examiner action | |
| 113 | 1,840* | 113 | 1,840* | Requesting publication of SIR after Examiner action | |
| 115 | 110 | 215 | 55 | Extension for reply within first month | |
| 116 | 390 | 216 | 195 | Extension for reply within second month | |
| 117 | 890 | 217 | 445 | Extension for reply within third month | |
| 118 | 1,390 | 218 | 695 | Extension for reply within fourth month | |
| 128 | 1,890 | 228 | 945 | Extension for reply within fifth month | |
| 119 | 310 | 219 | 155 | Notice of Appeal | |
| 120 | 310 | 220 | 155 | Filing a brief in support of an appeal | |
| 121 | 270 | 221 | 135 | Request for oral hearing | |
| 138 | 1,510 | 138 | 1,510 | Petition to institute a public use proceeding | |
| 140 | 110 | 240 | 55 | Petition to revive – unavoidable | |
| 141 | 1,240 | 241 | 620 | Petition to revive - unintentional | |
| 142 | 1,240 | 242 | 620 | Utility issue fee (or reissue) | |
| 143 | 440 | 243 | 220 | Design issue fee | |
| 144 | 600 | 244 | 300 | Plant issue fee | |
| 122 | 130 | 122 | 130 | Petitions to the Commissioner | |
| 123 | 130 | 123 | 130 | Petitions related to provisional applications | |
| 126 | 180 | 126 | 180 | Submission of Information Disclosure Stmt | |
| 581 | 40 | 581 | 40 | Recording each patent assignment per property (times number of properties) | 40.00 |
| 146 | 710 | 246 | 355 | For filing a submission after final rejection (see 37 CFR 1.129(a)) | |
| 149 | 710 | 249 | 355 | For each additional invention to be examined (see 37 CFR 1.129(b)) | |
| 179 | 710 | 279 | 355 | Request for Continued Examination (RCE) | |
| 169 | 900 | 169 | 900 | Request for expedited examination of a design application | |

Other fee (specify) ____________________ ______

Other fee (specify) ____________________ ______

**SUBTOTAL (3) $ 40.00**

*Reduced by Basic Filing Fee Paid

**SUBMITTED BY:**

**Typed or Printed Name:** Jeffrey S. Smith

**Signature:** Jeffrey S. Smith **Date:** November 28, 2000

**Reg. Number:** 39,377 **Telephone Number:** 408-720-8300

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11-28-2000
(Date signed)

Serial/Patent No.: * *
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- ☐ Other: ____

Attorney Docket No. 80398.P386 *PATENT*

UNITED STATES PATENT APPLICATION

FOR

# ROBUST TIME DOMAIN BLOCK DECODING


First Named Inventor:
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PREPARED BY:

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Tina Domingo
(Typed or printed name of person mailing paper or fee)

11-28-2000
(Signature of person mailing paper or fee) Date

## ROBUST TIME DOMAIN BLOCK DECODING

FIELD OF INVENTION

This invention is related to the field of signal transmission and error recovery.

BACKGROUND OF THE INVENTION

Common techniques for image compression, such as MPEG and JPEG, rely on blocked transforms. Though good for compression, these standard methods do not offer robust reconstruction techniques. Real world images tend to concentrate most of their energy in the low frequency bands. That is, most of the information content is stored in the low frequency coefficients of the transformed image. Packing this information into these relatively few coefficients has proved advantageous in image compression algorithms. Providing that these low frequency coefficients are transmitted correctly, an image can be recovered with high fidelity.

However, the cost of transforming an $N$-by-$N$ image segment to or from the frequency domain requires approximately $2N^3$ operations. If $N$ is large, this becomes infeasible. To keep the complexity manageable, $N$ is usually chosen to be a small number, e.g. 8, and the image is transformed one block at a time. In this way, the number of operations grows only linearly with the size of the image.

Block transforms which are also unitary are particularly attractive for transform encoding of an image because the mean-square contribution of a coefficient in the frequency domain equals its mean-square contribution in the time domain. For the encoder, this means that the larger a coefficient's magnitude is in the frequency domain, the larger its contribution to the time domain reconstruction.

In the same way, errors in the frequency domain correspond in magnitude to errors in the time domain.

One drawback of the conventional transform encoding methods is that they are not robust to errors. This lack of robustness is partially attributable to the variable length methods of compression usually used in the encoding, and partially attributable to the lack of correlation between components in the frequency domain. The loss of synchronization due to variable length coding can be overcome by adding resynchronization points, or by using a pseudo-fixed length encoding. However, the lack of correlation in the frequency domain is a more fundamental problem that has not been adequately addressed by conventional encoding methods.

Other researchers, notably Edward Chang and Keng-Kuan Lin, "Error Concealment and Reconstruction Schemes for Image Transmission on a Wireless Network," Stanford University, March 1997 and Sheila S. Hemami, "Reconstruction-Optimized Lapped Orthogonal Transforms for Robust Image Transmission," Cornell University, April 1996, have investigated the problem of lack of correlation in the frequency domain in the past. These researchers addressed this problem by estimating lost frequency components using weighted averages of corresponding components from surrounding blocks.

However, this process is fundamentally limited by the ever decreasing correlation encountered with increasing block size. For example, if the DC component is damaged, trying to estimate it by averaging surrounding DC coefficients is similar to estimating a lost pixel from a small image by averaging surrounding pixels. Because the image formed from the DC components is small compared to the original, the spatial correlation is low. Therefore, the averaging process is not effective.

## SUMMARY OF THE INVENTION

A method for robust time domain block decoding is disclosed. In one embodiment, the method includes receiving a block of transform domain coefficients, and associated error flags, decoding pixel values from the transform domain coefficients, determining a first estimate for each erroneous pixel value, and updating the decoded pixel values.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements, and in which:

**Figure 1** shows an embodiment of a block of image data.

**Figure 2** shows an embodiment of a pixel adjacent to pixels from other blocks.

**Figures 3** and **4** show embodiments of a method for recovering lost data.

**Figure 5** shows an embodiment of a device to recover lost data corresponding to the method in **Figure 4**.

**Figure 6** shows an embodiment of a system that includes a device to recover lost data.

**Figure 7** shows an embodiment of an image to block mapping.

**Figure 8** shows another embodiment of an image to block mapping.

DETAILED DESCRIPTION

A method for robust time domain block decoding is disclosed. In one embodiment, the method includes receiving a block of transform domain coefficients, and corresponding error flags, decoding pixel values from the transform domain coefficients, determining a first estimate for each erroneous pixel value, solving a constrained minimizing problem and updating the decoded pixel values.

To overcome the problem of lack of correlation in the frequency domain, the method for robust time domain block decoding reformulates the loss in the time domain and then exploits the correlation of the highest possible resolution to recover each lost coefficient. Because the highest resolution data is used regardless of the block size, the performance does not decrease with increasing block size.

Robust time domain block decoding implements a robust method for decoding block data in the time domain to reduce the effect of errors. Unlike previous methods, the transform used in robust time domain block decoding is based on a time domain formulation parameterized by scalar coefficients that can be estimated by solving a least squares problem. Examples of block transforms that can be included in the method to perform robust time domain block decoding include the DCT and the Haar Wavelet Transform.

The mathematical formulation used to describe robust time domain block decoding is discussed below. To facilitate this discussion, the following notation is reviewed. Boldface type is used to indicate a matrix or vector and regular type is used to indicate components. For example, $\mathbf{A} \in R^{N \times N}$ indicates that **A** is a *N*-by-*N* matrix with real components $A_{i,j}$, $i,j \in \{0,1,\ldots, N-1\}$. A superscript *T*, such as $\mathbf{A}^T$ indicates transposition. The inverse of **A** is $\mathbf{A}^{-1}$ and the inverse of the transposition of **A** is $\mathbf{A}^{-T}$.

Time domain formulation

Let $\mathbf{X} \in R^{N \times N}$ be a matrix of pixels, $\mathbf{H} \in R^{N \times N}$ be a non-singular transformation matrix, and $\mathbf{Y} \in R^{N \times N}$ be the result of the following transformation:

$$\mathbf{Y} = \mathbf{H}\mathbf{X}\mathbf{H}^T \tag{1}$$

$N^2$ indicator matrices $\mathbf{C}^{(k)} \in R^{N \times N}$ are defined as

$$C_{i,j}^{(k)} = \begin{cases} 1 & : \text{ if } k = iN + j \\ 0 & : \text{ otherwise} \end{cases} \tag{2}$$

and the vector $\mathbf{y}$ with $N^2$ components is defined as a one-dimensional rearrangement of the matrix $\mathbf{Y}$ such that

$$y_k = Y_{i,j}, \; k=iN+j \tag{3}$$

The matrix $\mathbf{Y}$ may be expanded as in terms of the vector $\mathbf{y}$ and the indicator matrices:

$$\mathbf{Y} = \sum_{k=0}^{N^2-1} y_k \mathbf{C}^{(k)}. \tag{4}$$

Inverting Eq. (1) and substituting Eq. (4), the image portion $\mathbf{X}$ may be recovered from the transformed pixels $\mathbf{Y}$ in the following way.

$$\begin{aligned} \mathbf{X} &= \mathbf{H}^{-1}\mathbf{Y}\mathbf{H}^{-T} && (5) \\ &= \mathbf{H}^{-1} \left( \sum_{k=0}^{N^2-1} y_k \mathbf{C}^{(k)} \right) \mathbf{H}^{-T} && (6) \\ &= \sum_{k=0}^{N^2-1} y_k (\mathbf{H}^{-1}\mathbf{C}^{(k)}\mathbf{H}^{-T}) && (7) \\ &= \sum_{k=0}^{N^2-1} y_k \mathbf{P}^{(k)} && (8) \end{aligned}$$

$\mathbf{P}^{(k)} \in R^{N \times N}$ is a rank one matrix attained from the outer product of columns $i$ and $j$ of the matrix $\mathbf{H}^{-1}$ where k = $i$N + j, $i,j$ = 0,...N-1. In the important special case when $\mathbf{H}$ is unitary, then

$$\mathbf{H}^{-1} = \mathbf{H}^{T} \qquad => \quad P^{(k)}_{p,q} = H_{i,p} H_{j,q}, \qquad k = iN + j \tag{9}$$

Eq. (8) is the basis for robust reconstruction. Suppose that some of the $y_k$ pixels have been lost in the communication channel. Neighboring relations from the decoded domain can be used to estimate the missing $y_k$.

Least squares recovery

Let $I = \{k_0, k_1, \ldots, k_{M-1}\}$ be a set containing the indices of the $M$ unknown values of $\mathbf{Y}$. Then, separate $\mathbf{X}$ into the known and unknown portions.

$$\mathbf{X} \quad = \quad \sum_{k \notin I}^{N^2-1} y_k \mathbf{P}^{(k)} + \sum_{k \in I}^{N^2-1} y_k \mathbf{P}^{(k)} \tag{10}$$

$$= \quad \hat{\mathbf{X}} + \sum_{k \in I}^{N^2-1} y_k \mathbf{P}^{(k)} \tag{11}$$

Although $\hat{\mathbf{X}}$ and $\mathbf{P}^{(k)}$ are known, $\mathbf{X}$ is not and $y_k$ cannot be solved directly. To overcome this, $E(\mathbf{X})$, the expected value of $\mathbf{X}$, is determined, based on local correlations, and is used in place of $\mathbf{X}$.

Because the prediction of the executed value is not perfect, Eq. (11) may not have a solution. Instead the following least squares problem is solved.

Least Squares Problem

Given a partial decoding $\hat{\mathbf{X}} \in R^{N \times N}$, a predicted decoding $E(\mathbf{X}) \in R^{N \times N}$, and a set of pre-determined matrices $\mathbf{P}^{(k)}$, find $y_k$, $\forall k \in I$ that minimizes

$$\left\| \hat{\mathbf{X}} + \sum_{k \in I}^{N^2=1} y_k \mathbf{P}^{(k)} - E(\mathbf{X}) \right\|_F^2 \qquad (12)$$

where the subscript $F$ indicates the Frobenius norm.

The solution of Eq. (12) is easily seen by rearranging the terms in vector form, where the Frobenius norm corresponds to the usual vector-2 norm. Let $\alpha = [y_{k_0}, y_{k_1}, \ldots, y_{k_{M-1}}] \in R^M$ be a column vector of the unknown values of $\mathbf{Y}$, and let $\mathbf{x}$ and $\hat{\mathbf{x}}$ be vector versions of $\mathbf{X}$ and $\hat{\mathbf{X}}$, respectively. The vector can now be expressed as the sum of a known vector, $\hat{\mathbf{x}}$ and a matrix-vector product

$$\mathbf{x} = \hat{\mathbf{x}} + \mathbf{F}\alpha \qquad (13)$$

where column $j \in \{0, \ldots, M-1\}$ of $F$ contains components of $\mathbf{P}^{(k)}$ rearranged in vector form. The minimization problem can now be written in terms of the unknown vector, $\alpha$. The function $f(\alpha)$ is minimized:

$$f(\alpha) = \left\| \hat{\mathbf{x}} + \mathbf{F}\alpha - E(\mathbf{x}) \right\|_2^2 \qquad (14)$$

$$= (\hat{\mathbf{x}} + \mathbf{F}\alpha - \mathrm{E}(\mathbf{x}))^{\mathrm{T}} (\hat{\mathbf{x}} + \mathbf{F}\alpha - \mathrm{E}(\mathbf{x})) \qquad (15)$$

$$= [\mathbf{F}\alpha + (\hat{\mathbf{x}} - \mathrm{E}(\mathbf{x}))]^T [\mathbf{F}\alpha + (\hat{\mathbf{x}} - \mathrm{E}(\mathbf{x}))] \qquad (16)$$

$$= \boldsymbol{\alpha}^{T}(\mathbf{F}^{T}\mathbf{F})\boldsymbol{\alpha} + 2(\hat{\mathbf{x}} - \mathrm{E}(\mathbf{x}))^{T}\mathbf{F}\boldsymbol{\alpha} + (\hat{\mathbf{x}} - \mathrm{E}(\mathbf{x}))^{T}(\hat{\mathbf{x}} - \mathrm{E}(\mathbf{x})) \tag{17}$$

At the unconstrained minimum, the gradient vanishes.

$$f'(\alpha) = 2(\mathbf{F}^{T}\mathbf{F})\boldsymbol{\alpha} + 2(\hat{\mathbf{x}} - \mathrm{E}(\mathbf{x}))^{T}\mathbf{F} = 0 \tag{18}$$

Therefore, an $\alpha$ that satisfies the following equation is determined.

$$(\mathbf{F}^{T}\mathbf{F})\boldsymbol{\alpha} = \mathbf{F}^{T}(\mathrm{E}(\mathbf{x}) - \hat{\mathbf{x}}) \tag{19}$$

Solution of Eq. (19) requires $O(M^3)$ floating point operations.

Determination of E(X)

To solve Eq. (12), it is necessary to have a first prediction of $E(\mathbf{X})$. To keep the complexity reasonable, $E(\mathbf{X})$ would likely be a unconstrained estimate of $\mathbf{X}$ based on surrounding pixels. This unconstrained estimate is used in Eq. (12) to estimate the missing $y_k$ coefficient values, so that the reconstructed $\mathbf{X}$ is constrained to be a sum of the known and unknown terms of $\mathbf{X}$ as formulated in Eq. (11).

The robustness of the decoder comes from the fact that an entire block of data is used to estimate each value of $y_k$. Nevertheless, the predicted value for $E(\mathbf{X})$ should be reasonably close to the actual expected value estimates of $y_k$. A simple and effective method to determine $E(\mathbf{X})$ is to form each image block by mapping subsamples of the image to the block and to use the average of adjacent pixels as the estimate for the missing pixel. This method is improved if the encoder uses a subsample block structure as indicated in **Figure 1**. The transform block of **Figure 1** includes samples from every other pixel of the image in both the horizontal and vertical directions. As indicated in **Figure 2**, each pixel of $E(\mathbf{X})$ may be calculated as the average of adjacent pixels, which are taken from other blocks. For example, a pixel, $x_1$, may be estimated using adjacent pixels $z_1$, $z_2$, $z_3$, and $z_4$ from other blocks.

Recovery Method

A method for recovering lost data is shown in **Figure 3**. A block of encoded image data is received by a decoder, 305. The image data is encoded in the transform domain, and is represented by transform domain coefficients. Some of the transform domain coefficients may be lost or damaged during transmission. Therefore, when the image is decoded, pixel values derived from the lost or damaged coefficients will be lost or damaged, 310. Each lost or damaged coefficient is identified, 315. An initial estimated value for each lost or damaged pixel is determined, 320. In one embodiment, the estimated pixel value is the expected value estimate, which is the average of the pixels adjacent to the lost or damaged pixel, as discussed above. This estimated pixel value is used to determine an initial value for each corresponding lost or damaged transform domain coefficient. The block of encoded image data is then decoded using the initial values of the transform domain coefficients, 325.

An updated value for each lost or damaged coefficient is then determined, 330. The updated coefficient value may be determined by minimizing a least squares problem. For example, an estimate of $\alpha$ that satisfies

$$(\mathbf{F}^T\mathbf{F})\boldsymbol{\alpha}=\mathbf{F}^T(\mathrm{E}(\mathbf{x})-\hat{\mathbf{x}}) \qquad \text{Equation (19)}$$

can be determined. This estimate of $\alpha$ can be used to update the estimates for the damaged pixel values, 335. Updating the pixel values may be performed by using

$$\mathbf{x} = \hat{\mathbf{x}} + \mathbf{F}\alpha \qquad \text{Equation (13)}$$

as discussed above. Therefore, updated estimates for the lost or damaged coefficients $Y_k$ can be determined using

$$\mathbf{X} = \hat{\mathbf{X}} + \sum_{k\in I}^{N^2-1} y_k \mathbf{P}^{(k)} \qquad \text{Equation (11)}$$

However, one or more pixels adjacent to a lost or damaged pixel may also be lost or damaged. The lost or damaged pixels adjacent to a given lost or damaged pixel will reduce the accuracy of the initial executed value estimate of the given lost or damaged pixel. Therefore, iterating the method of **Figure 3** over the entire image will further improve the estimated value.

<u>Refinement of $E(\mathbf{X})$</u>

If the pixels adjacent to pixels of **X** are error-free, then $E(\mathbf{X})$ is easily determined. However, the adjacent pixels may also be erroneous. In this case, one iteration of the method of **Figure 3** over the entire image will improve these damaged adjacent pixels. Improvement in these pixels will yield a corresponding improvement in $E(\mathbf{X})$. This enables a resolution of Eq. (12), to calculate improved values of $y_k$. Thus, when adjacent blocks contain errors, iteration on the entire image may yield improvement to the image.

Alternative Recovery Method

Based on the previous equations, another embodiment of a robust decoding algorithm is shown in **Figure 4**. The method of **Figure 3** is repeated for a given number of iterations. The encoded image data is received by the decoder in the transform domain, 405. The damaged or lost coefficients for each block of the image are initially set to their expected value, 410. The image data is decoded using the initial values of the coefficients, 415. Then, for each block, updated values for the lost or damaged coefficients are determined, 420.

The updated values are used to update the pixel values of the decoded image, 430. A delay may occur to enable updated values for each block of the image to be determined, 435. Steps 405 through 435 may then be repeated to further improve the decoded image for a given number of iterations, 440.

The method of **Figure 4** uses a fixed number of iterations which makes for a simple hardware implementation of a decoder using a cascade structure, as shown in **Figure 5**. The delays may be included in the system to allow time for the neighboring blocks to be updated before $E(\mathbf{X})$ is recomputed. However, it is not necessary to rigidly adhere to a prescribed number of iterations. Iteration may be stopped at any time without harm. Furthermore, if there are no adjacent block errors, the iteration has no effect.

As shown in **Figure 5**, input image data is received by logic 510 which receives the image and reconstructs the transform blocks in the scanning order. The reconstructed image is sent to logic 520, which decodes each N by N block. Also, logic 530 detects any errors present in the N by N block. The block is received by logic 540 which determines updated values for the transform block. Delay logic 540 enables time for the neighboring blocks to be decoded before further refining the updated values of the N by N block. Then, logic 550 updates the values of the transform block using data from the neighboring blocks to enhance the resolution.

Delay logic 560 enables time for the neighboring blocks to be decoded, and logic 570 updates the values of the N by N block again, then outputs the image data.

Hardware Overview

The signal encoding, transmission, and subsequent decoding are performed by the apparatus illustrated in **Figure 6.** Signal 600 is a data stream input to Encoder 610. Encoder 610 follows a compression algorithm, such as an Adaptive Dynamic Range Coding ("ADRC") compression algorithm for example. A further description of ADRC encoding and buffering is disclosed in U.S. Patent no. 4,722,003 entitled "High Efficiency Coding Apparatus" and U.S. Patent no. 4,845,560 also entitled "High Efficiency Coding Apparatus", assigned to the assignee of the present invention. The encoder generates Packets 1, . . .N for transmission along Transmission Media 635. Decoder 620 receives Packets 1, . . . N from Transmission Media 635 and generates Signal 630. Signal 630 is a reconstruction of Signal 600.

Encoder 610 and Decoder 620 can be implemented a variety of ways to perform the encoding and decoding functions. In one embodiment, Encoder 610 and/or Decoder 620 are embodied as software stored on media and executed by a general purpose or specifically configured computer system, typically including a central processing unit, memory and one or more input/output devices and co-processors. Alternatively, the Encoder 610 and/or Decoder 620 may be implemented as hardware logic circuits to perform these functions. In addition, Encoder 610 and/or Decoder 620 can be implemented as a combination of hardware, software or firmware. Furthermore, the decoder shown in **Figure 5** may be used to implement decoder 610 shown in **Figure 6.**

In one embodiment, Signal 600 is a color video image having a sequence of video frames, each frame including information representative of an image for an

interlaced video system. Each frame is composed of two fields, wherein one field contains data of the even lines of the image and the other field containing the odd lines of the image. The data includes pixel values which describe the color components of a corresponding location in the image. For example, in one embodiment, the color components consist of the luminance signal Y, and color difference signals U, and V. It is readily apparent that the process of the present invention can be applied to signals other than interlaced video signals. Furthermore, it is apparent that the present invention is not limited to implementations in the Y, U, V color space, but can be applied to images represented in other color spaces.

Referring back to **Figure 6**, Encoder 610 divides the Y, U, and V signals and processes each group of signals independently in accordance with the compression algorithm. The following description, for purposes of simplifying the discussion, describes the processing of the Y signal; however, the encoding steps are replicated for the U and V signals.

In one embodiment, Encoder 610 groups Y signals across two subsequent frames, referred to herein as a frame pair, of Signal 600 into three dimensional blocks ("3D") blocks. For one embodiment, a 3D block is generated from grouping two 2D blocks from the same localized area across a given frame pair, wherein a two dimensional 2D block is created by grouping localized pixels within a frame or a field. It is contemplated that the process described herein can be applied to different block structures. The grouping of signals will be further described in the image-to-block mapping section below.

In one embodiment, a single frame includes 5280 2D blocks wherein each 2D block comprises 64 pixels. Thus, a frame pair includes 5280 3D blocks as a 2D block from a first frame and a 2D block from a subsequent frame are collected to form a 3D block.

Image-to-Block Mapping

The subsample block structure of **Figure 1** used to estimated E(X) can be formed by mapping subsamples of an image to the block structure, as shown in **Figures 7** and **8**. Image-to-block mapping is performed for the purpose of dividing a frame or frame set of data into 2D blocks or 3D blocks respectively. Moreover, image-to-block mapping includes using a complementary and/or interlocking pattern to divide pixels in a frame to facilitate robust error recovery during transmission losses.

**Figure 7** illustrates one embodiment of an image-to-block mapping process for an exemplary 16 pixel section of an image. Image 700 comprises 16 pixels forming a localized area of a single frame. Each pixel in Image 700 is represented by an intensity value. For example, the pixel in the top left hand side of the image has an intensity value equal to 100 whereas the pixel in the bottom right hand side of the image has intensity value of 10.

In one embodiment, pixels from different areas of Image 700 are used to create 2D Blocks 710, 720, 730, and 740. 2D Blocks 710, 720, 730, and 740 are encoded, shuffled (as illustrated below), and transmitted. Subsequent to transmission, 2D Blocks 710, 720, 730, and 740 are recombined and used to form Image 750. Image 750 is a reconstruction of Image 700.

To ensure accurate representation of Image 700 despite a possible transmission loss, **Figure 7** is an interlocking complementary block structure, one embodiment of which is illustrated in **Figure 7**, is used to reconstruct Image 750. In particular, the pixel selection used to create 2D Blocks 710, 720, 730, and 740 ensures that a complementary and/or interlocking pattern is used to recombine the blocks when Image 750 is reconstructed. Accordingly, when a particular 2D block's

attribute is lost during transmission, contiguous sections of Image 750 are not distorted during reconstruction.

**Figure 1** and **Figure 8** illustrate other complementary and interlocking 2D block structures. Other structures may also be utilized. Similar to **Figure 7**, these 2D block structures illustrated in **Figure 8**, ensure surrounding 2D blocks are present despite transmission losses for a given 2D block. However, Patterns 810a, 810b, and 810d use horizontal and/or vertical shifting during the mapping of pixels to subsequent 2D blocks. Horizontal shifting describes shifting the tile structure in the horizontal direction a predetermined number of pixels prior to beginning a new 2D block boundary. Vertical shifting describes shifting the tile structure in the vertical direction a predetermined number of pixels prior to beginning a new 2D block boundary. In application, horizontal shifting only may be applied, vertical shifting may only be applied, or a combination of horizontal and vertical shifting may be applied.

Pattern 810a illustrates a spiral pattern used for image-to-block mapping. The spiral pattern follows a horizontal shifting to create subsequent 2D blocks during the image-to-block mapping process. Patterns 810a and 810d illustrate complementary patterns wherein pixel selection is moved by a horizontal and vertical shifting to create subsequent 2D blocks during the image-to-block mapping process. Further, Patterns 810b and 810d illustrate alternating offsets on pixels selection between 2D blocks. Pattern 810c illustrates using an irregular sampling of pixels to create a 2D block for image-to-block mapping. Accordingly, the image-to-block mapping follows any mapping structure provided a pixel is mapped to a 2D block only once.

**Figure 7** and **Figure 8** describe image-to-block mapping for 2D block generation. It is readily apparent that the processes are applicable to 3D blocks. As described above, 3D block generation follows the same boundary definition as a 2D

block, however the boundary division extends across a subsequent frame resulting in a 3D block. In particular, a 3D block is created by collecting the pixels used to define a 2D block in a first frame together with pixels from a 2D block in a subsequent frame. In one embodiment, both pixels in the 2D block from the first frame and the 2D block from the subsequent frame are from the exact same location.

These and other embodiments of the present invention may be realized in accordance with these teachings and it should be evident that various modifications and changes may be made in these teachings without departing from the broader spirit and scope of the invention. The specification and drawings are, accordingly, to be regarded in an illustrative rather than restrictive sense and the invention measured only in terms of the claims.

CLAIMS

What is claimed is:

1. A method comprising:

receiving a block of transform domain coefficients and corresponding error flags;

estimating an initial value for each erroneous coefficient;

decoding pixel values of the block, using the initial values of the coefficients where there are errors;

updating the value for each erroneous coefficient; and

updating pixel values of the block using the updated values of the coefficients.

2. The method of claim 1, wherein estimating an initial value further comprises estimating the expected value of each erroneous coefficient.

3. The method of claim 1, wherein decoding pixel value further comprises applying the transform domain coefficients to a transform.

4. The method of claim 1, wherein updating the value for each erroneous coefficient further comprises minimizing a least squares equation.

5. The method of claim 1 further comprising:

displaying the updated pixel values.

6. An apparatus comprising:

means for receiving a block of transform domain coefficients and corresponding error flags;

means for estimating an initial value for each erroneous coefficient;

means for decoding pixel values of the block using the initial values of the coefficients where there are errors;

means for updating the value for each erroneous coefficient; and

means for updating pixel values of the block using the updated values of the coefficients.

7. The apparatus of claim 6, wherein said means for estimating an initial value further comprises means for estimating the expected value of each erroneous coefficient.

8. The apparatus of claim 6, wherein said means for decoding pixel values further comprises means for applying the transform domain coefficients to a transform.

9. The apparatus of claim 6, wherein said means for updating the value of each erroneous coefficient further comprises means for minimizing a least squares equation.

10. The apparatus of claim 6 further comprising:

means for displaying the updated pixel values.



11. A computer readable medium having instructions which, when executed by a processing system, cause the system to:

receive a block of transform domain coefficients and corresponding error flags;

estimate an initial value for each erroneous coefficient;

decode pixel values of the block using the initial values of the coefficients where there are errors;

update the value for each erroneous coefficient; and

update pixel values of the block using the updated values of the coefficients.

12. The medium of claim 11, wherein the executed instructions further cause the system to:

estimate the initial value by estimating the expected value of each erroneous coefficient.

13. The medium of claim 11, wherein the executed instructions further cause the system to:

decode pixel values by applying the transform domain coefficients to a transform.

14. The medium of claim 11, wherein the executed instructions further cause the system to:

update the value for each erroneous coefficient by minimizing a least squares equation.

15. The medium of claim 11 wherein the executed instructions further cause the system to:

display the updated pixel values.

## ABSTRACT

A method for robust time domain block decoding is disclosed. In one embodiment, the method includes receiving a block of transform domain coefficients, detecting errors in one or more transform domain coefficients, decoding pixel values from the transform domain coefficients, determining a first estimate for each erroneous pixel value, and updating the decoded pixel values.

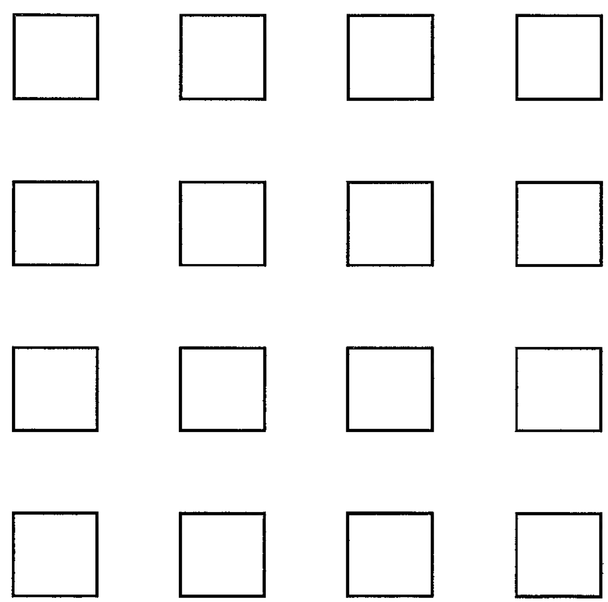


FIG. 1

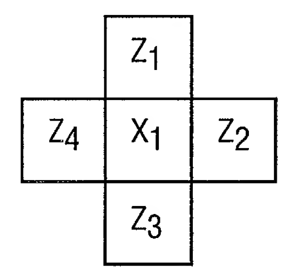



FIG. 2

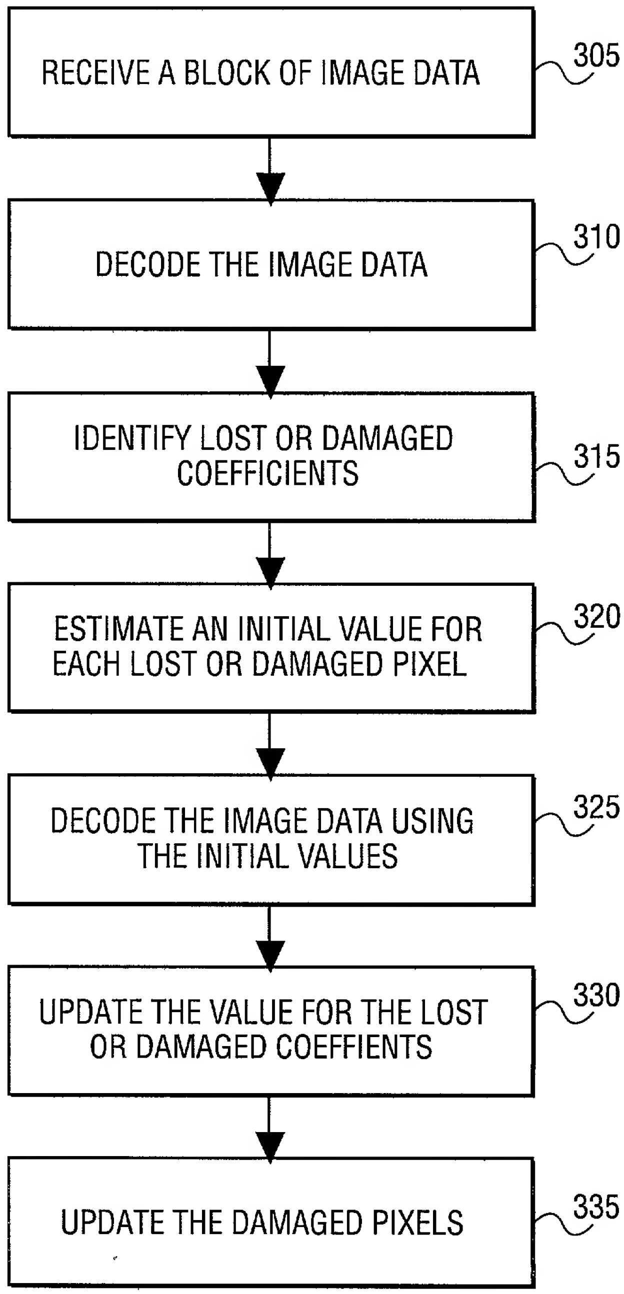

RECEIVE A BLOCK OF IMAGE DATA
305
DECODE THE IMAGE DATA
310
IDENTIFY LOST OR DAMAGED COEFFICIENTS
315
ESTIMATE AN INITIAL VALUE FOR EACH LOST OR DAMAGED PIXEL
320
DECODE THE IMAGE DATA USING THE INITIAL VALUES
325
UPDATE THE VALUE FOR THE LOST OR DAMAGED COEFFIENTS
330
UPDATE THE DAMAGED PIXELS
335

FIG. 3

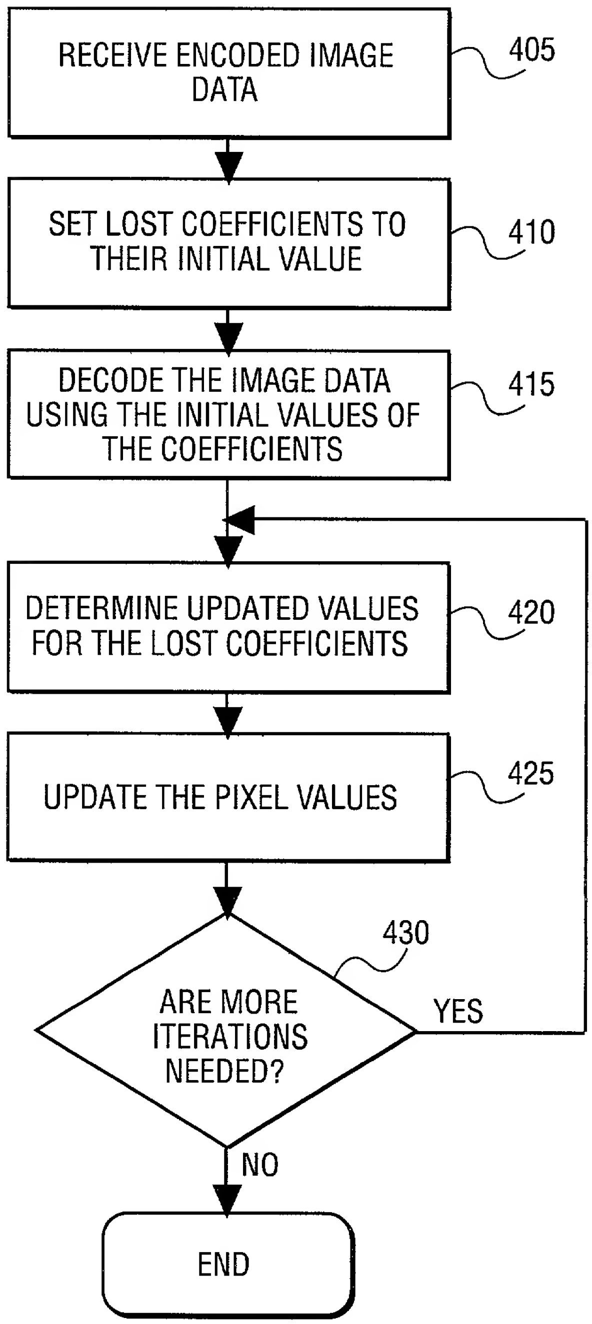

RECEIVE ENCODED IMAGE DATA
405
SET LOST COEFFICIENTS TO THEIR INITIAL VALUE
410
DECODE THE IMAGE DATA USING THE INITIAL VALUES OF THE COEFFICIENTS
415
DETERMINE UPDATED VALUES FOR THE LOST COEFFICIENTS
420
UPDATE THE PIXEL VALUES
425
430
ARE MORE ITERATIONS NEEDED?
YES
NO
END

FIG. 4

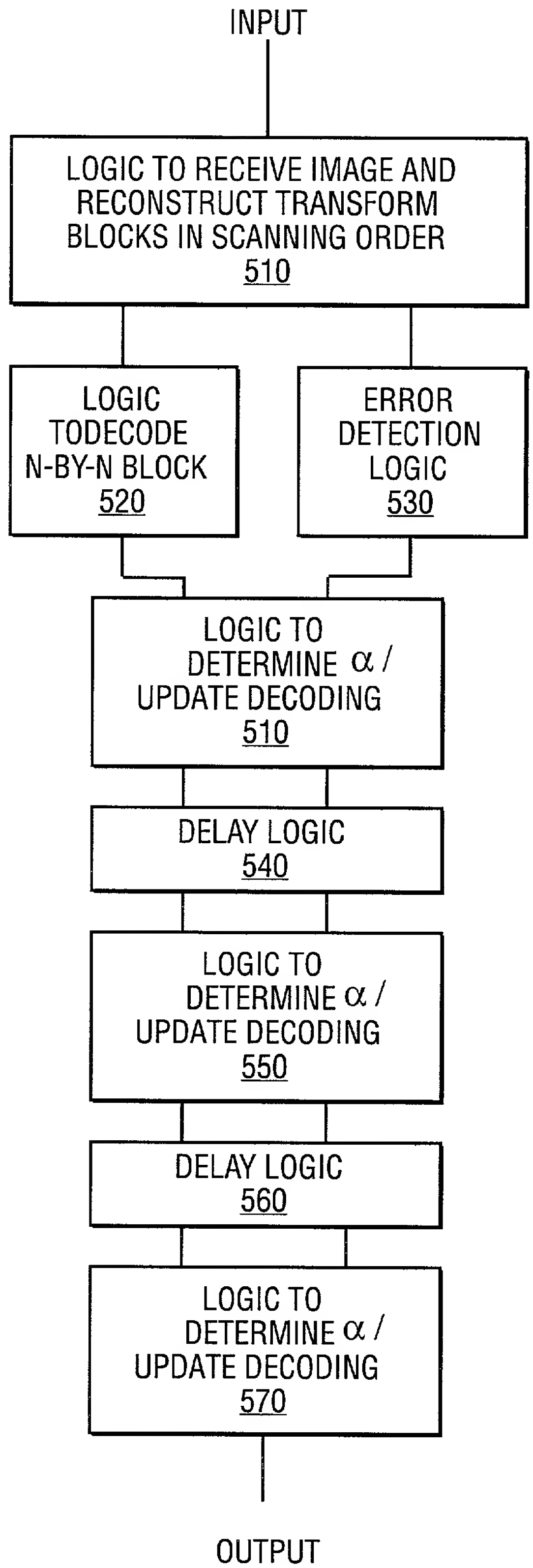

INPUT
LOGIC TO RECEIVE IMAGE AND RECONSTRUCT TRANSFORM BLOCKS IN SCANNING ORDER 510
LOGIC TODECODE N-BY-N BLOCK 520
ERROR DETECTION LOGIC 530
LOGIC TO DETERMINE α / UPDATE DECODING 510
DELAY LOGIC 540
LOGIC TO DETERMINE α / UPDATE DECODING 550
DELAY LOGIC 560
LOGIC TO DETERMINE α / UPDATE DECODING 570
OUTPUT

FIG. 5

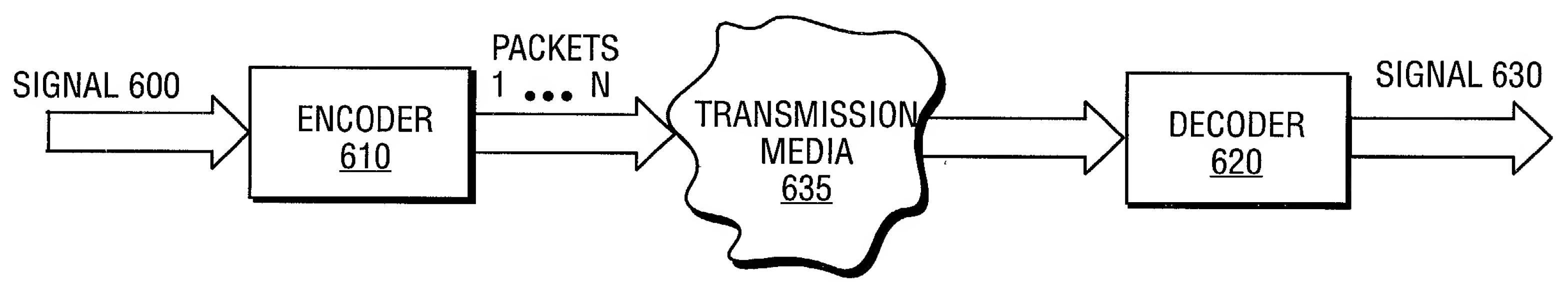
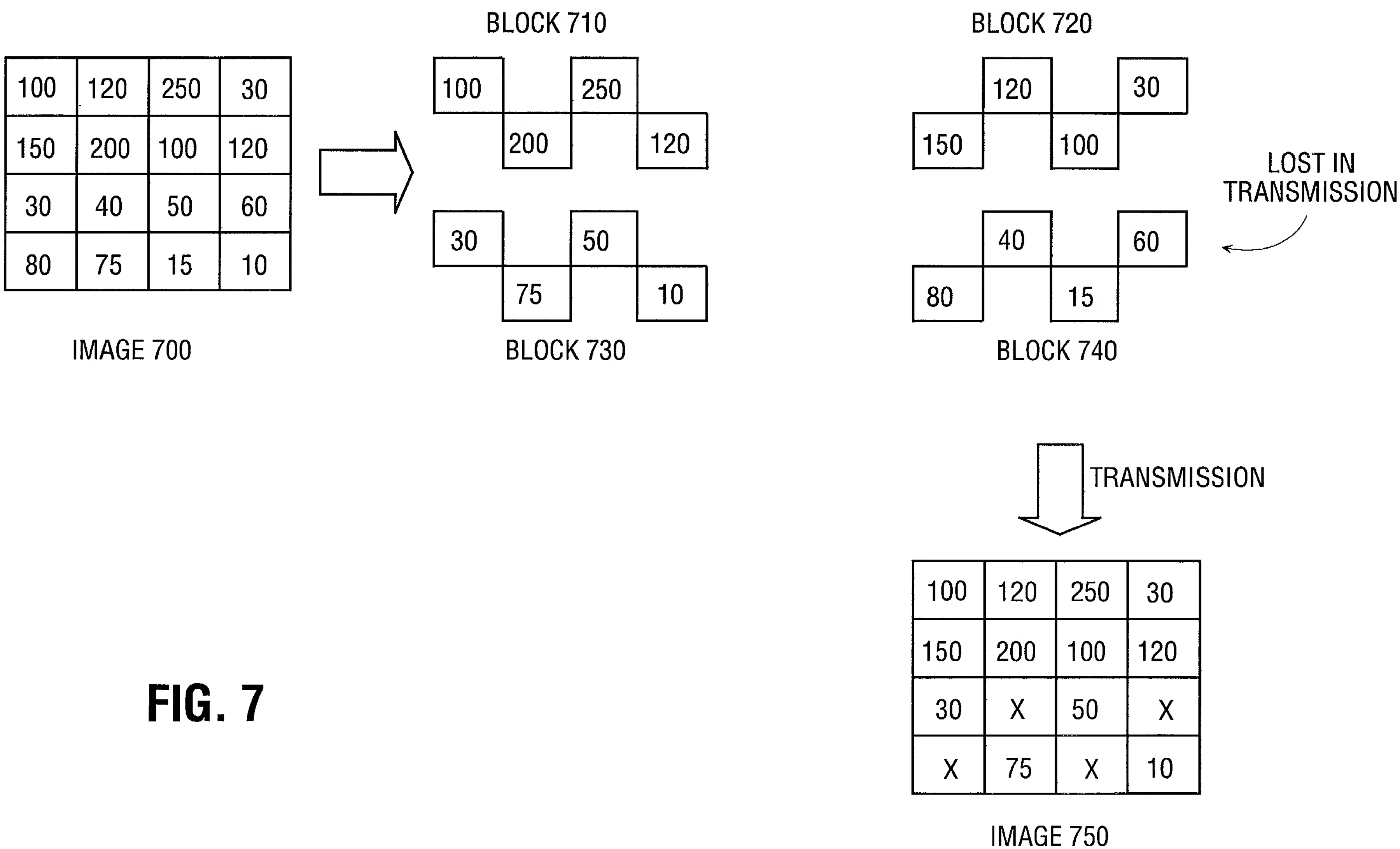
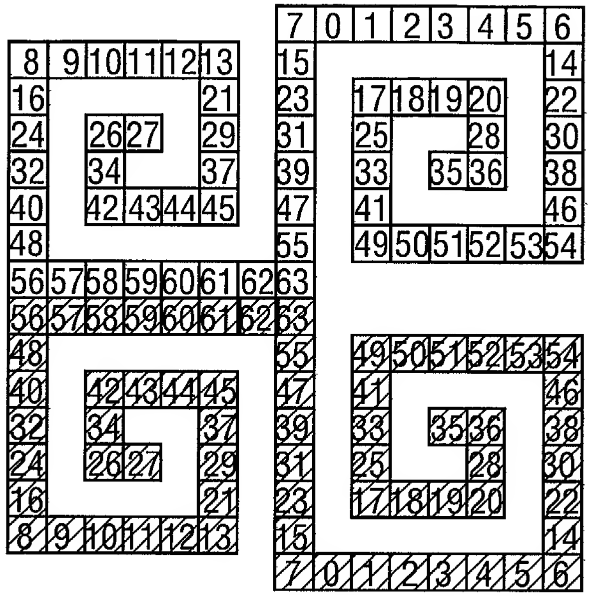

SIGNAL 600
ENCODER
610
PACKETS
1 ••• N
TRANSMISSION
MEDIA
635
DECODER
620
SIGNAL 630

FIG. 6

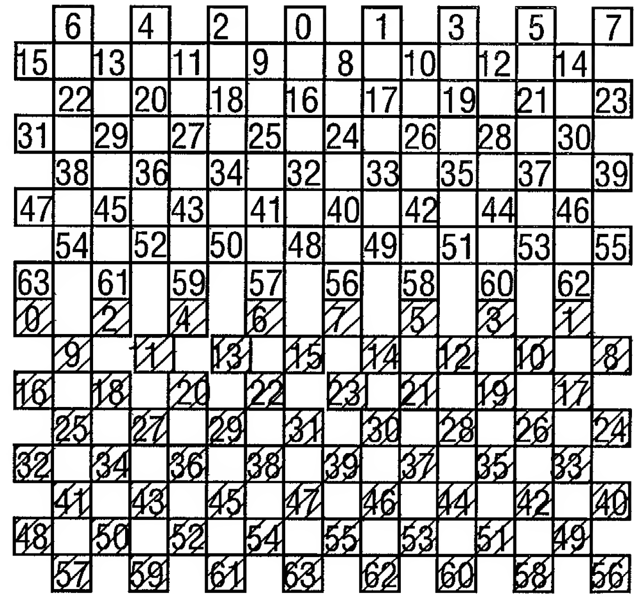


100
120
250
30
150
200
100
120
30
40
50
60
80
75
15
10
IMAGE 700
BLOCK 710
100
250
200
120
BLOCK 730
30
50
75
10
BLOCK 720
120
30
150
100
BLOCK 740
40
60
80
15
LOST IN TRANSMISSION
TRANSMISSION
100
120
250
30
150
200
100
120
30
X
50
X
X
75
X
10
IMAGE 750

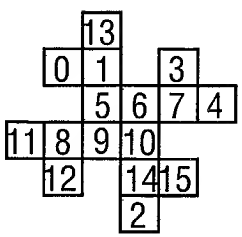

FIG. 7



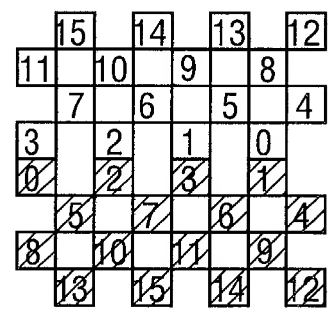
810a



810b



810c



810d

**FIG. 8**

Attorney's Docket No.: 80398.P386 Patent

## DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below, next to my name.

I believe I am the original, first, and sole inventor (if only one name is listed below) or an original, first, and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

**ROBUST TIME DOMAIN BLOCK DECODING**

the specification of which

X is attached hereto.
__ was filed on (MM/DD/YYYY) ________________ as
United States Application Number ____________
or PCT International Application Number ____________
and was amended on (MM/DD/YYYY) ____________.
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claim(s), as amended by any amendment referred to above. I do not know and do not believe that the claimed invention was ever known or used in the United States of America before my invention thereof, or patented or described in any printed publication in any country before my invention thereof or more than one year prior to this application, that the same was not in public use or on sale in the United States of America more than one year prior to this application, and that the invention has not been patented or made the subject of an inventor's certificate issued before the date of this application in any country foreign to the United States of America on an application filed by me or my legal representatives or assigns more than twelve months (for a utility patent application) or six months (for a design patent application) prior to this application.

I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d), of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s) — Priority Claimed

| | | | | |
|---|---|---|---|---|
| (Number) | (Country) | (Foreign Filing Date - MM/DD/YYYY) | Yes | No |
| (Number) | (Country) | (Foreign Filing Date - MM/DD/YYYY) | Yes | No |
| (Number) | (Country) | (Foreign Filing Date - MM/DD/YYYY) | Yes | No |

I hereby claim the benefit under title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below:

(Application Number) (Filing Date – MM/DD/YYYY)

(Application Number) (Filing Date – MM/DD/YYYY)

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Number) (Filing Date – MM/DD/YYYY) (Status -- patented, pending, abandoned)

(Application Number) (Filing Date – MM/DD/YYYY) (Status -- patented, pending, abandoned)

I hereby appoint the persons listed on Appendix A hereto (which is incorporated by reference and a part of this document) as my respective patent attorneys and patent agents, with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith.

**Send correspondence to** Jeffrey S. Smith, **BLAKELY, SOKOLOFF, TAYLOR &**
**(Name of Attorney or Agent)**
**ZAFMAN LLP, 12400 Wilshire Boulevard 7th Floor, Los Angeles, California 90025 and direct telephone calls to** Jeffrey S. Smith, **(408) 720-8300.**
**(Name of Attorney or Agent)**

**I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.**

Full Name of Sole/First Inventor James J. Carrig

Inventor's Signature James J. Carrig Date Nov. 27, 2000

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## APPENDIX A

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## APPENDIX B

Title 37, Code of Federal Regulations, Section 1.56
Duty to Disclose Information Material to Patentability

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclosure information exists with respect to each pending claim until the claim is cancelled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is cancelled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclosure all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

(1) Prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) The closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made or record in the application, and

(1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the applicant takes in:

(i) Opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

(1) Each inventor named in the application;

(2) Each attorney or agent who prepares or prosecutes the application; and

(3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent, or inventor.